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CHAPTER 5.4

DIE CASTINGS

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THE PROCESS

Die casting involves the injection, under high pressure and with high velocity, of molten metal into a split metal die. Zinc, lead, and tin alloys, with melting points below 390°C (730°F), are cast in a “hot-chamber” die-casting machine, as shown in Fig. 5.4.1, whose injection pump can be immersed continuously in the molten material. Because molten aluminum dissolves ferrous parts, aluminum alloy is cast in a “cold-chamber” machine, whose design avoids continuous molten-metal contact by using a ladle to introduce molten metal to the machine.

Dies, even those for castings of simple shape, are complex mechanisms with many moving parts. The die must be rugged enough to withstand metal injection pressures of up to 69 MPa (10,000 lbf/in²), yet it must also reproduce fine surface detail in the casting. Larger dies are usually cooled by channeling water behind the heavier casting sections and inside cores.

Casting removal is accomplished by ejector pins bearing on the casting’s face. The pins are advanced after the casting has solidified sufficiently.

Production die castings are almost always die-trimmed, using a special hardened-steel tool shaped to match the actual casting to remove peripheral parting-line flash, in-gates, gates to overflow pads, and, as the design requires, flash in cored holes and openings. If pressure tightness is required, the castings may be impregnated with sodium silicate or organic compounds.

CHARACTERISTICS

Process Advantages

1. High rate of production.
2. High accuracy in sustaining dimensions part to part.

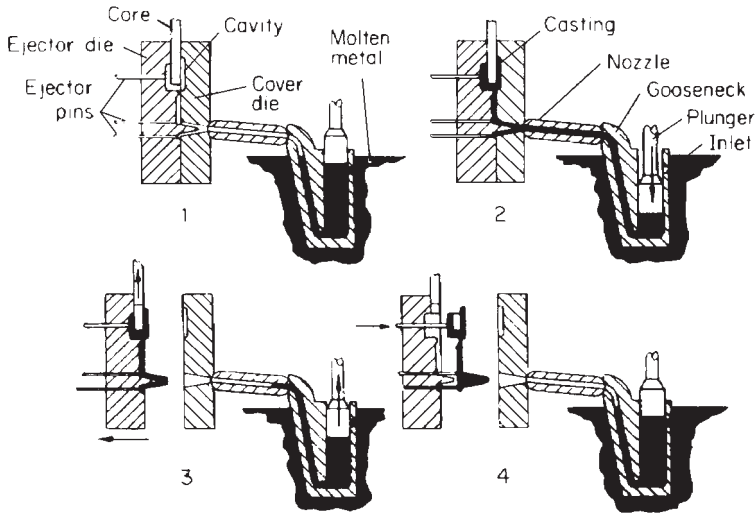


FIGURE 5.4.1 Operating sequence of the hot-chamber die-casting machine: (1) Die is closed, and hot chamber (gooseneck) is filled with molten metal. (2) Plunger injects molten metal through gooseneck and nozzle and into the die cavity. Metal is held under pressure until it solidifies. (3) Die opens, and core slides, if any, retract. Casting stays in the ejector half of the die. Plunger returns, pulling molten metal back through nozzle and gooseneck. (4) Ejector pins push casting out of ejector half of the die. As plunger uncovers the inlet, molten metal refills gooseneck. (Courtesy Aluminum Industrie Vaasen.)

3. Smooth surface finishes for minimum mechanical finishing or surfaces simulating a wide variety of textures.
4. Ability to incorporate such cast-in details as holes, openings, slots, trademarks, numbers, etc.
5. Intricate shapes and details at no greater cost than if they were omitted (once the die has been made), thus often making it attractive for the designer to incorporate two or more components in one die casting.
6. Thinner walls than can be produced with other casting processes.
7. The process uses a range of alloys that fit many design requirements: zinc for intricate form and platability; aluminum for higher structural strength, rigidity, and light weight; brass for still higher strength and corrosion resistance; and magnesium for good strength with extra lightness and superior machinability.
8. Ability to cast in inserts such as pins, studs, shafts, linings, bushings, fasteners, strengtheners, and heating elements.
9. Ability to cast pressure-tight parts.

Process Limitations

1. Dies are complicated and expensive, particularly if they have moving elements for coring details, so that lower casting prices usually can pay for the tooling only at

high rates of usage.

2. Microporosity is common in die castings because the die is filled rather violently and solidification begins in less than $\frac{1}{5}$ s; air and vaporized die lubricant can become trapped in the cavity. With a well-designed part and good die design, porosity can be reduced to a harmless level, but highly stressed parts having heavy sections and bosses may give trouble nevertheless. Designers should allow for lower tensile strengths in such areas. Also, because pockets of porosity can produce surface blisters, heat treatment of parts or use in environments above 200°C (400°F) should be avoided. (Also see below under “Wall Thickness.”)
3. Undercuts cannot be incorporated in simple two-piece dies. When they are essential, they often can be added by using core slides (moving die elements), but they add to the die’s cost and also may increase the casting price by slowing production rates.
4. Owing to the very high metal pressures, sand cores or collapsing metal cores cannot normally be used, so some “hollow” shapes are not readily die-castable. In special situations for which the added cost is justified, zinc core pieces of the appropriate shape, incorporating undercuts, can be used and subsequently melted out by heating the casting to 390°C (730°F).
5. Size is limited at the upper level by equipment availability. Today, this is about 3000-ton locking pressure, for a top limit of about 30 kg (65 lb) for zinc, 45 kg (100 lb) for aluminum, and 16 kg (35 lb) for magnesium die castings, and a maximum effective area (less openings) of about 0.77 m² (1200 in²) including the metal-distribution system to the cavity.
6. The alloys having the most attractive properties for the designer are often those with the least castability, so the list of alloys that can be processed with maximum economy is restricted. Alloys with high melting temperatures are not practicable for die castings.
7. Flash is always present except in very small zinc die castings; its removal may present an economic burden.
8. To get the part out of the die, taper, or draft, is needed. Thus walls and other details cannot normally be made perpendicular to the parting line except through use of expensive core slides.

APPLICATIONS

Die casting is a preferred process for making nonferrous-metal parts of intricate shape for such mass-production items as automobiles, appliances, outboard motors, hand tools, builders’ hardware, electronics parts, electric switchgear, computer peripherals, business machines, optical and photographic equipment, and toys. Figures 5.4.2 and 5.4.3 illustrate typical die-cast components.

ECONOMIC PRODUCTION QUANTITIES

In large-volume situations, tooling cost is subordinate to piece price, and it is in these

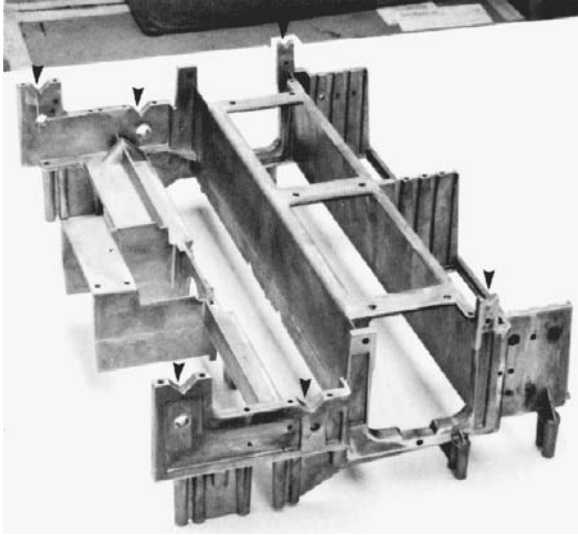


FIGURE 5.4.2 This one-piece die-cast chassis for a high-speed serial electronic printer illustrates the possibility of combining a number of parts to eliminate machining and assembly costs. The die casting replaces 82 separate components and fasteners in the forerunner assembly. Drilling and tapping have been eliminated by incorporating cored holes, most of which receive thread-forming screws for fastening. The part is used as die-trimmed and deburred, secondary machining having been completely eliminated. (Courtesy Diablo Systems, Inc., a Xerox Company.)



FIGURE 5.4.3a These aluminum die castings for a motorcycle engine show how good design can provide ribs where needed for strength and cored holes for fastening while maintaining fairly constant wall thickness. (Courtesy Aluminum Industrie Vaasen.)

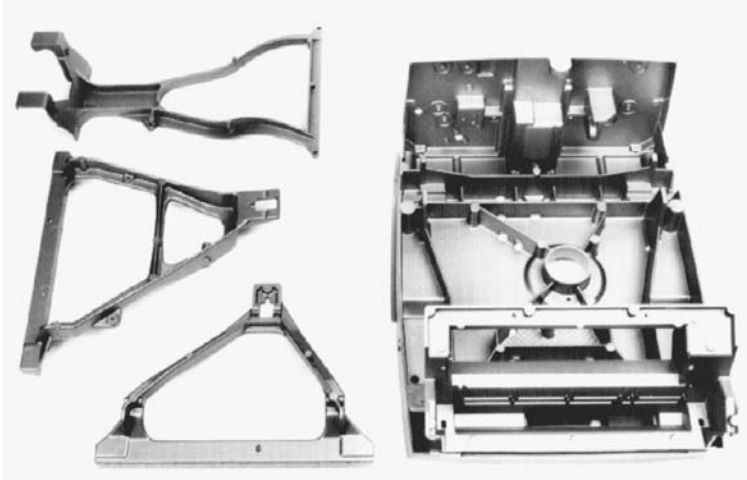


FIGURE 5.4.3b These die-cast aluminum components for a weight scale demonstrate intelligent use of ribbing to promote strength and stiffness. (*Courtesy Aluminum Industrie Vaasen.*)

situations that die casting is most advantageous. At the other end of the scale, where die cost must be amortized over a small number of parts, it is desirable to evaluate closely overall costs, including machining, in relation to costs that would be incurred with other manufacturing methods. Often a total quantity in the range of 5000 to 10,000 pieces can justify the tooling cost.

Die-casting dies are relatively expensive; the greater the dimensional accuracy and detail specified in the drawing, the more the die will cost. A simple insert die for a small straightforward part can be very modest in cost, whereas a self-contained die for a complex part such as an automotive automatic-transmission housing will involve an expenditure well into hundreds of thousands of dollars.

Die life is a significant aspect of the economics of die casting because of the die's cost. Typically, a die for aluminum or magnesium parts will last for about 125,000 shots, a zinc die is good for 1 million or more shots, and a brass die will last only for 5000 to 50,000 shots, depending on the weight of the casting and/or die material.

Die-casting production rates are high. Typically, a 0.5-kg (1-lb) aluminum die casting having a projected area of 320 cm² (50 in²) can be produced at the rate of about 100 per hour, while a large, complex 9-kg (20-lb) part might run 10 or 15 pieces per hour. Casting rates for magnesium are somewhat faster than for aluminum. Zinc-casting rates are more than double the rates for aluminum on parts of similar size because zinc need not be ladled in the hot-chamber machine, runs at a lower temperature, and uses readily automated equipment.

Flash removal adds to the cost of die casting. Die trimming is a fairly inexpensive means of removal, but a trimming die must be built, increasing the cost of the tooling package. There is an economic break-even point, often at the level of 10,000 to 20,000 castings over the life of the die, below which it is preferable to remove flash by hand sanding or filing, or both.

The designer should make adequate allowance, in planning a product-introduction date, for the fairly long lead times needed for die design and construction. A simple insert die usually can be built and tried out, the samples subjected to dimensional

analysis, and the die corrected within 8 weeks. A complex die will take 30 weeks or more for the same procedures. And there is no way in which these intervals can be appreciably shortened: Die making is on a 40- to 50-h workweek schedule, not normally subject to speedup by use of a second shift.

SUITABLE MATERIALS

Because of limitations in the hot-work tool steels available for die construction, die castings are made from the lower-melting-point nonferrous materials. By far the most popular are aluminum and zinc alloys, which account for over 90 percent of total production.

Aluminum is predominant for larger die castings because of its lower cost. Zinc is preferred for smaller castings, for which its superior castability outweighs the materials-cost factor. Other materials are more restricted in use: magnesium because of its relatively high cost and other factors, brass because of its relatively high melting point [910°C (1670°F)] and resulting shortening of the life of costly tooling, and lead and tin because of material cost and relatively low mechanical properties.

In recent years, ferrous-metal die casting has been carried out on an experimental and limited-production basis. High melting temperatures of about 1700°C (3100°F) are involved, and these necessitate the use of special refractory metals for dies and a number of special procedures. The process is most advantageous for difficult-to-machine tool steels, alloy steels, and stainless steels.

Table 5.4.1 lists the most suitable alloys for die casting with information about their typical applications, melting points, and tensile strength.

GENERAL DESIGN CONSIDERATIONS

The designer is urged to study the overall function of the product and consider the possibility that several functions can be incorporated into one die casting, with integral features for attachment and assembly, as typified by the chassis illustrated in Fig. 5.4.2. Full advantage also should be taken of opportunities for the reduction of machining that die casting affords.

Dies, after being machined, must finally be hardened by heat treating, which makes subsequent alterations difficult. It is therefore important for the product designer to finalize the best design for the die-cast part and reach agreement with the die caster on the producibility of the design before the die itself is designed and construction begins.

The designer also should consider ejector-pin locations early in production design, preferably in consultation with the die caster. If the impressions left by the pins are not tolerable or cannot be hidden in a cored-out zone, alternatives such as ring or sleeve ejection are available, but they are more costly to incorporate into the die than pins.

Abrupt section changes, sharp corners, and walls at an acute angle to one another disturb the continuity of metal flow and promote porosity and surface irregularities. Therefore, radii should be as generous as possible, with differing sections blending into one another. Blind recesses in the die, such as are needed to form bosses, tend to cause subsurface porosity because of trapped air. This can cause drills to wander and taps to break in secondary machining and should therefore be avoided.

TABLE 5.4.1 Alloys Recommended for Die Casting

Material	Alloy designation		Melting point, °C(°F)	Ultimate tensile strength, kPa (lbf/in ²)*	Castability	Remarks
	Commercial	UNS				
Aluminum	380	A03800	593 (1100)	317,000 (46,000)	Excellent	Most popular aluminum alloy; best combination of properties and ease of use
	383	A03830	582 (1080)	310,000 (45,000)	Excellent	Higher-silicon version of 380; used when thin walls and pressure tightness are required
	360	A03600	596 (1105)	303,000 (44,000)	Good	Used when better corrosion resistance and ductility are required
Zinc	AG40A (Zamak No. 3)	Z33520	387 (729)	283,000 (41,000)	Excellent	Used for the majority of commercial applications for thin walls and good platability
	AZ91B	M11913	596 (1105)	234,000 (34,000)	Excellent	Used for the majority of commercial applications for lightness with strength
Brass	858	C85800	899 (1650)	379,000 (55,000)	Fair	Used when high strength, elongation, and corrosion resistance are required

*The typical values indicated are for separately die-cast test bars and do not represent values for specimens cut from die castings.

Simulation software, in conjunction with computer-aided design (CAD) programs, is increasingly becoming available to designers of die castings. It can aid in optimizing materials flow and cooling of the casting in the die. Sometimes, casting design changes result from such a simulation, providing an improvement in the part's castability and a reduction in production problems.

SPECIFIC DESIGN RECOMMENDATIONS

Wall Thickness

The easiest die casting to make and the soundest in terms of minimum porosity is one that has uniform wall thickness. Sharp changes in sectional area or heavy sections over 6 mm ($\frac{1}{4}$ in) thick should be avoided if possible. When a heavy section seems to be indicated, its underside should be cored out.

The skin of a die casting is its strongest part. The injected liquid metal chills rapidly on contact with die cavity surfaces, resulting in a fine-grained, dense structure generally devoid of porosity. This skin measures between 0.38 and 0.63 mm (0.015 and 0.025 in) thick, depending on casting size. Thus the strength-to-weight ratio of die-cast sections improves quickly as wall thickness is reduced, to the point where it is maximized when the wall is "all skin," i.e., from 0.75 to 1.3 mm (0.030 to 0.050 in) thick.

Table 5.4.2 indicates the minimum-wall-thickness ranges, by alloy classification, for varying single-surface areas that can be achieved consistently and economically.

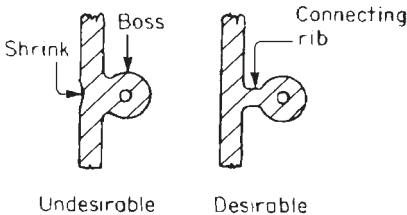


FIGURE 5.4.4 To avoid surface shrinks, relocate the boss and connect it to the wall with a short rib.

Heavy bosses behind the surface can cause visible "sinks" on decorative parts having flat, expansive areas. These marks are caused by shrinkage of the relatively large mass of metal in the boss during cooling after the adjacent walls have been frozen, which draws the wall in toward the boss. The effect is magnified with thinner walls. Shrinks become a problem when the part is plated or painted, since these treatments accentuate surface irregularities. When a boss must be so located, the shrinkage problem may be

TABLE 5.4.2 Die-Casting Wall Thicknesses

Surface area, cm ² (in ²)*	Minimum recommended wall thickness, mm (in)		
	Zinc alloys	Aluminum and magnesium alloys	Copper alloys
Up to 25 (4)	0.38–0.75 (0.015–0.030)	0.75–1.3 (0.030–0.050)	1.5–2.0 (0.060–0.080)
25–100 (4–15)	0.75–1.3 (0.030–0.050)	1.3–1.8 (0.050–0.070)	2.0–2.5 (0.080–0.100)
100–500 (15–80)	1.3–1.8 (0.050–0.070)	1.8–2.2 (0.070–0.090)	2.5–3.0 (0.100–0.120)
500–2000 (80–300)	1.8–2.2 (0.070–0.090)	2.2–2.8 (0.090–0.110)	
2000–5000 (300–800)	2.2–4.6 (0.090–0.180)	2.8–6.3 (0.110–0.250)	

*The area of a single, separately identifiable plane to be cast at the stated wall thickness.

mitigated by moving the boss away from the wall and connecting it to the wall with a short rib of the same thickness, as shown in Fig. 5.4.4.

Zinc die-casting technology has recently been developed to reduce minimum wall thickness considerably below Table 5.4.2 values, to as low as 0.38 mm (0.015 in) in limited zones for parts in the 25- to 100-cm² (4- to 15-in²) size range. This specialized procedure has appeal mainly to high-volume industries because the much more sophisticated and therefore more expensive tooling and production processing that are involved must be offset by materials-cost savings in large-scale production. The designer should confer with the die caster before tackling “thin-walled zinc” part design.

Ribs and Fillets

Ribs are mainly incorporated into a die casting to reinforce it structurally, replacing heavy sections that would be otherwise necessary. (See Figs. 5.4.5 and 5.4.6.) They should be perpendicular to the parting line to allow for casting removal from the die, although external ribs running parallel to the parting line can be incorporated by using core slides.

To avoid sinks, ribs should be no wider than the thickness of the casting wall and

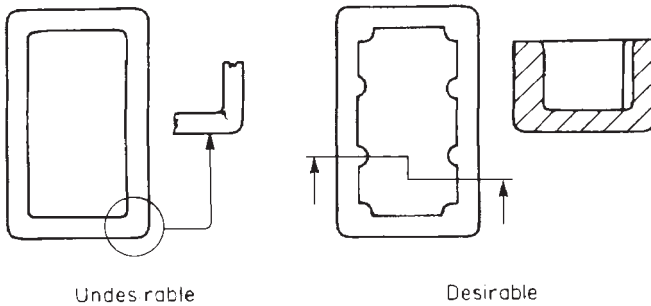


FIGURE 5.4.5 Box-shaped components are strengthened by incorporating internal ribs that run the full depth of the part. Corners are reinforced by radiusing to avoid corner fractures in the casting.

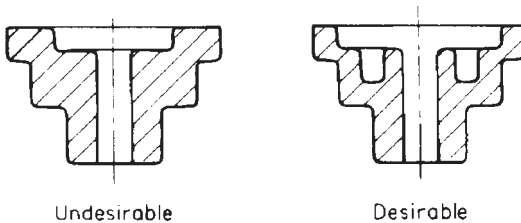


FIGURE 5.4.6 Where there would normally be a heavy section adjacent to a cored area, introduce further coring to create ribs, thereby removing mass and obtaining uniform wall thick-

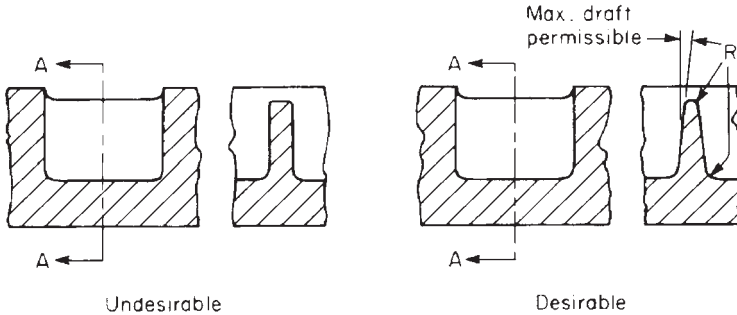


FIGURE 5.4.7 Provision of maximum draft eases ejection of deep ribs from the die.

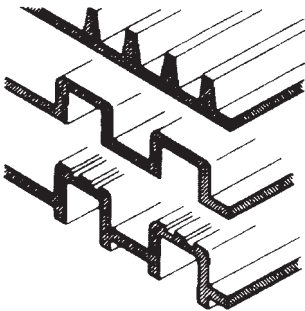


FIGURE 5.4.8 Ribbing of various forms used

no higher than 4 times their width for complete filling and ease of removal from the die. The minimum distance between two adjacent ribs should be the sum of their heights. Ample draft (at least 2° per side) also helps with ejection (see Fig. 5.4.7).

Ribs and fillets are also used to improve the rigidity and strength of standing bosses. Ribs need not be designed all on one side of a wall to strengthen it; they can be formed in both halves of the die, as shown in the lower two illustrations of Fig. 5.4.8. The rib is then part of the wall, strengthening it without thickening it locally.

ening it locally.

If ribs are designed to cross, they should do so at right angles. Acute-angle intersections cause the die to overheat in the area between the ribs. Multiple intersections of radial ribs should be avoided; otherwise, the intersection will contain porosity. (These rules are identical to those for other casting processes and are illustrated in Figs. 5.1.9 and 5.1.10.)

Ribs are fairly easy to incorporate into an existing hardened die by using electrical-discharge machining (EDM) techniques. Thus the designer may underdesign initially, test sample castings, then add strength if necessary by removal of die steel until the optimum combination of mechanical properties and casting-material conservation is reached. This is preferable to overdesigning and having to lighten the die casting later by welding the die, which is a costly, life-limiting procedure.

Draft

The sidewalls of die castings and other features perpendicular to the parting line must be tapered, or drafted, as much as possible to facilitate removal from the die. When the draft angle is abnormally small, even the slightest depression in the drafted surface of the die will prevent ejection without causing drag marks in the surface of the casting.

TABLE 5.4.3 Draft Requirements for Die Castings

Depth of wall, mm (in)	Draft angle for inside wall, °*			
	Copper alloys	Aluminum alloys	Magnesium alloys	Zinc alloys
0.25–0.50 (0.01–0.02)	18	16	13	10
0.50–1.0 (0.02–0.04)	14	12	10	7
1.0–2.0 (0.04–0.08)	10	8	7	5
2.0–3.8 (0.08–0.15)	7	6	5	3.5
3.8–7.5 (0.15–0.3)	5	4	3.5	2.5
7.5–15 (0.3–0.6)	3.5	3	2.5	1.8
15–25 (0.6–1.0)	2.5	2.2	2	1.5
25–50 (1.0–2.0)	2	1.5	1.5	1
50–100 (2.0–4.0)	1.3	1	1	0.7
100–175 (4.0–7.0)	1	1	0.7	0.5
175–250 (7.0–10.0)	1	0.7	0.6	0.5

*For outside walls, one-half of the above angles may be used.

Source: Data taken from ADCI-E4-65, American Die Casting Institute.

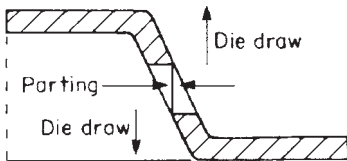


FIGURE 5.4.9 When a die casting's wall slopes sufficiently, through holes can sometimes be formed by using "kissing cores" built into opposite die halves.

Draft angle depends on the alloy and varies inversely with wall depth, as shown in Table 5.4.3. Although this table indicates that the draft required on outside walls is one-half the draft for inside walls, the designer should, if possible, specify the inside angle for the outside as well and be as liberal as possible in the selection of angle.

The designer may use draft in another way, as shown in Fig. 5.4.9, to incorporate a side hole without resorting to a core slide in the die. When details in opposite die halves come together or "shut off" at an angle to form an opening, as in this illustration, the angle should be no less than 5° from the vertical to avoid galling at the shutoff zone.

Radii

Sharp internal corners in a die casting are to be avoided for several reasons. As the alloy shrinks on the core, induced stresses are concentrated at the corner instead of being distributed through the surrounding mass, thus weakening the part and perhaps even causing it to fracture. The abrupt change in metal-flow direction during injection also can produce subsurface porosity at the corner to weaken this area further. Sharp edges on cores are difficult to maintain because they are points of heat concentration, with resulting premature erosion of the die material.

Sharp external corners are undesirable because they become a localized point of heat and stress buildup in the die steel that can cause die cracking and early failure. Therefore, radii and fillets should be as generous as possible, preferably at least $1\frac{1}{2}$ times wall thickness for both inside and outside radii. (See Figs. 5.4.10 and 5.4.11.)

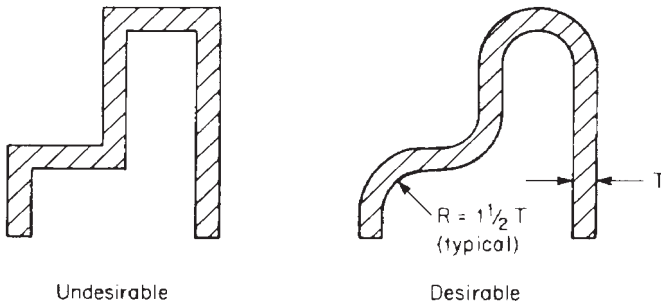


FIGURE 5.4.10 Allow generous radii at internal and external corners.

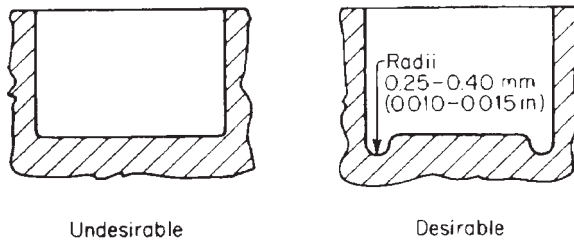


FIGURE 5.4.11 Sharp corners in the die cavity concentrate die stresses and shorten die life.

Holes

The die-casting process can accommodate the coring in of holes into the body of the casting at right angles to the parting line. However, there are core-length limits, depending on diameter, that should not be exceeded. (See Table 5.4.4.) Long, slender cores lead to excessive core breakage. Cores also must be drafted adequately to ensure their longevity. (See Table 5.4.5.) A lower limit on core diameter of 3 mm (0.120 in) for aluminum and magnesium and 1.5 mm (0.060 in) for zinc should be observed, since smaller cores are prone to frequent breakage and erosion from heat buildup.

TABLE 5.4.4 Optimum Greatest Depth of Cored Holes as Related to Diameter*

	Diameter of hole, mm (in)								
	3 (1/8)	4 (3/32)	5 (3/16)	6 (1/4)	10 (3/8)	13 (1/2)	16 (5/8)	19 (3/4)	25 (1)
Alloy	Maximum depth, mm (in)								
Zinc†	10 (3/8)	14 (9/16)	19 (3/4)	25 (1)	38 (1 1/2)	50 (2)	80 (3 1/8)	115 (4 1/2)	150 (6)
Aluminum†	8 (5/16)	13 (1/2)	16 (5/8)	25 (1)	38 (1 1/2)	50 (2)	80 (3 1/8)	115 (4 1/2)	150 (6)
Magnesium†	8 (5/16)	25 (1)	16 (5/8)	25 (1)	38 (1 1/2)	50 (2)	80 (3 1/8)	115 (4 1/2)	150 (6)
Copper				13 (1/2)	25 (1)	32 (1 1/4)	50 (2)	90 (3 1/2)	125 (5)

*Requirements for tapped holes are shown in Table 5.4.6.

†For cores larger than 25 mm (1 in) in diameter the diameter depth shall be 1:6.

TABLE 5.4.5 Draft Requirements for Cored Holes in Die Castings

Depth of hole, mm (in)	Draft,°			
	Copper alloys	Aluminum alloys	Magnesium alloys	Zinc alloys
1.5–2.5 (0.06–0.1)	11	10	8	6
2.5–5 (0.1–0.2)	9	8	7	4.5
5–10 (0.2–0.4)	7	6	5	3
10–20 (0.4–0.8)	5	4	3.5	2.5
20–38 (0.8–1.5)	3.5	3	2.5	1.8
38–75 (1.5–3)	3	2	1.8	1.3
75–150 (3–6)	2	1.5	1	0.9

Source: From ADCI-E7-65, American Die Casting Institute.

When small-diameter cores are needed several inches apart in a casting face, consideration should be given to incorporating design features such as cored-out recesses that will support casting shrinkage in the spans between cores. Otherwise the delicate cores will have to absorb these forces, with possible resulting bending and breakage.

Table 5.4.6 provides recommended diameters for die-cast holes to be tapped without prior drilling.

Since cores incorporated into moving slides are also denied the benefit of an ejection system to move the casting off them, they need as much draft as possible to minimize casting distortion when the slide is withdrawn.

Cores are fitted through the die block and should not be located closer than about 3 mm ($\frac{1}{8}$ in) to a cavity wall. Otherwise, local weakening in the steel can result in die cracking and premature failure.

In designing for consistent walls and weight reduction, it is best to avoid a situation requiring sliding cores. If possible, the part should be designed so that it can be made in a simple two-piece die. (See Fig. 5.4.12.)

Through-wall cored holes for tapping should be countersunk on both sides, as shown by Fig. 5.4.13.

Concentricity requirements are important in designing for cored details. If a central core and a circle of holes are to be concentric, they should be designed so that they can all be cored from the same die half.

Designers are urged to take advantage of the economies offered through use of thread-forming screws. Such fasteners roll their own thread, avoiding the need to tap into cored holes and, unlike thread-cutting (self-tapping) screws, generate no chips. Core diameters are somewhat greater than for tapped holes, so the manufacturer's recommendations should be followed.

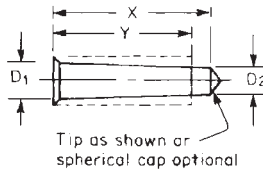
Holes and openings in sidewalls parallel to the parting line usually require a slide to carry the core, which adds appreciably to the die's cost and slows casting-cycle time. Two designs that handle this situation without a slide are shown in Figs. 5.4.9 and 5.4.14.

Core Slides

It is always preferable to locate a core slide at the parting line even if it means stepping the parting line to accommodate the core's centerline. Flash that inevitably forms

TABLE 5.4.6 Cored Holes for Tapping

When required, cored holes in zinc, magnesium, and aluminum die castings may be tapped without removing the draft by drilling. Recommended sizes for tapping are based upon allowing 75% of full depth of thread at bottom or small end of the cored hole and 60% at the top or large end of the cored hole.



Tap size†		Dimensions, in			
		Hole diameters‡		Maximum threaded depth of hole Y	Maximum depth of cored hole X
		D ₁	D ₂		
0.138	6-40 NF	0.119	0.114	0.208	0.270
0.138	6-32 NC	0.113	0.107	0.162	0.240
0.164§	8-36 NF	0.142	0.134	0.321	0.390
0.164§	8-32 NC	0.140	0.133	0.307	0.385
0.190	10-32 NF	0.165	0.159	0.380	0.458
0.190	10-24 NC	0.158	0.150	0.380	0.482
0.216	12-28 NF	0.188	0.181	0.432	0.519
0.216	12-24 NC	0.184	0.176	0.432	0.534
	¼-28 NF	0.222	0.215	0.500	0.587
	¼-20 NC	0.211	0.201	0.500	0.625
	⅜-24 NF	0.280	0.272	0.625	0.727
	⅜-18 NC	0.269	0.259	0.625	0.762
	½-24 NF	0.343	0.334	0.750	0.852
	½-16 NC	0.326	0.314	0.750	0.906
	⅝-20 NF	0.398	0.388	0.875	1.000
	⅝-14 NC	0.382	0.368	0.875	1.053
	¾-20 NF	0.461	0.451	1.000	1.125
	¾-13 NC	0.440	0.425	1.000	1.192
	⅞-18 NF	0.519	0.508	1.125	1.262
	⅞-12 NC	0.497	0.481	1.125	1.333
	1-18 NF	0.582	0.571	1.250	1.387
	1-11 NC	0.554	0.536	1.250	1.497
	1-16 NF	0.701	0.689	1.500	1.656
	1-10 NC	0.672	0.652	1.500	1.750
	1-14 NF	0.819	0.804	1.750	1.928
	1-9 NC	0.789	0.767	1.750	2.027
	1-14 NF	0.944	0.929	2.000	2.178
	1-8 NC	0.903	0.878	2.000	2.312

*From ADCI Standard E8-65, American Die Casting Institute.

†NF = national fine; NC = national coarse.

‡These dimensions are subject to ±0.002-in tolerance for ⅜-in or smaller diameters and ±0.003-in tolerance for larger diameters.

§Minimum sizes recommended for aluminum or magnesium alloys.

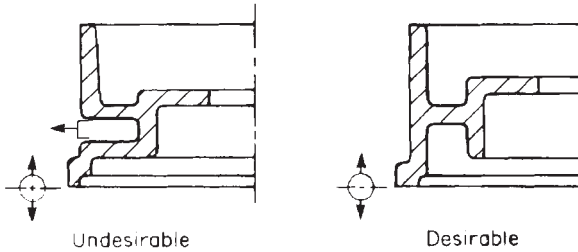


FIGURE 5.4.12 Avoid external-wall undercuts and the need to incorporate core slides in designing for weight reduction.

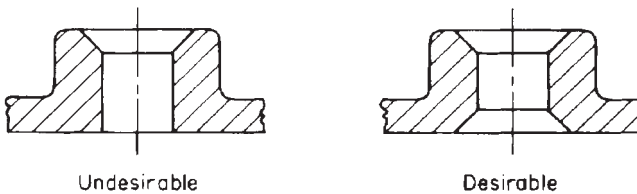


FIGURE 5.4.13 Countersink on both sides any through holes that are to be tapped in order to avoid a deburring operation where the tap emerges.

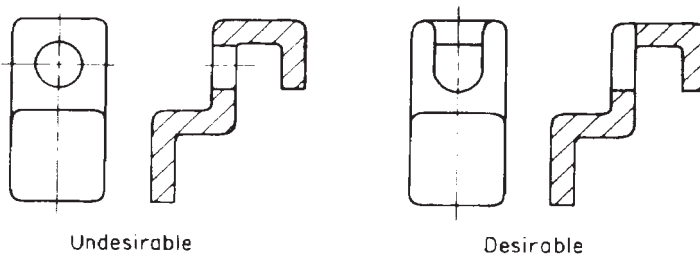


FIGURE 5.4.14 Core slides can be avoided by using this hole design.

around the slide is then ejected with the casting, whereas with cores that are “submerged” below the parting line, the flash may shear off in place when the casting is ejected to cause heavy wear in the slide’s ways and possible seizure. A further drawback of submerged cores is the difficulty of getting a die-release agent to them.

A sliding core should never be designed to intersect the opposite die half, since imperfect die closure (possibly the result of flash at the parting plane not being fully removed) would result in a damaged die. It is preferable, in the situation of Fig. 5.4.15, to core through the outside wall only and plan on drilling the inside holes.

Threads

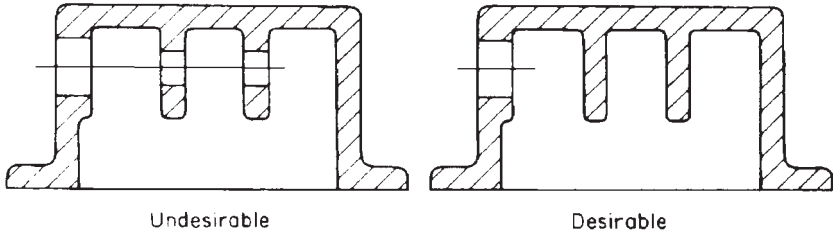


FIGURE 5.4.15 Avoid designing for core slides that must fit accurately through both die halves. Drill holes in internal ribs.

External screw threads can be formed on die castings, but when a precision fit is required, it is recommended that the threads be machined. In less demanding situations, the die-casting process can produce acceptable external threads in several ways, the most practical of which is to cut the thread between the die halves and eject the part in the normal manner. Accuracy will be affected to the extent that the die halves may be misaligned, and for this reason pitches finer than 24 threads per inch for aluminum and magnesium and 32 threads per inch for zinc are not recommended.

Die trimming such a part by using tooling shaped to the thread profile seldom produces a good finish, again because of the slight die mismatch customarily encountered.

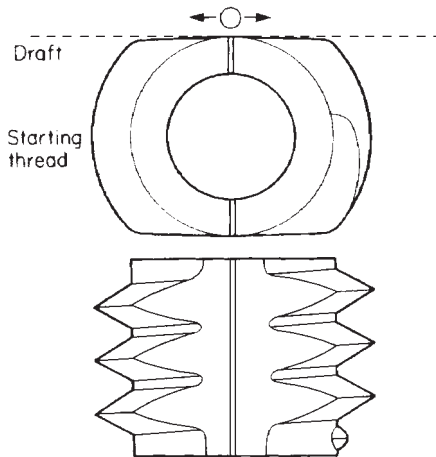


FIGURE 5.4.16 Trimming die castings that have cast-in threads at the parting line is simplified when this design is used.

tered. Figure 5.4.16 shows another thread form having flats at each side that can be readily trimmed along a straight line. Although the die cavity becomes more expensive, the extra cost is usually offset by a more acceptable product that is easier to deflash.

It is possible to die-cast internal threads by using techniques that involve either unscrewing the casting from a threaded core or rotating the core out of the casting during ejection. Such a design should be confined to zinc parts, since the other alloys

shrink more tightly onto cores and the draft needed for release affects thread function.

Inserts

Inserts can be incorporated in die-cast parts where necessary, though with increased cycle time because of the time required to load inserts into the die. The most common type of insert is the threaded stud used for assembly. It must be designed so that material will shrink onto its shank with sufficient force to prevent movement in use. Figure 5.4.17 illustrates various forms that will resist both axial and rotational forces. The

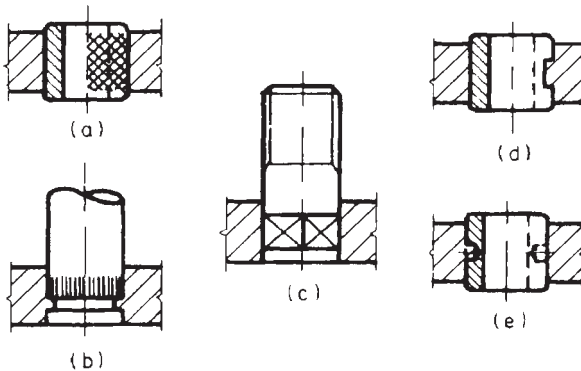


FIGURE 5.4.17 Insert designs to prevent rotation and pullout: (a) knurled circumferences; (b) recess and longitudinal grooves; (c) machined and undercut square; (d) localized machined flats; (e) drilled anchor holes.

insert must have a very precise fit into its retaining recess in the die block, and the insert's threads must be kept away from the casting face; otherwise, they will load up with metal. Positive location within the die must be provided to prevent insert movement during the casting cycle.

Machining Allowance

When a die casting requires a machining operation, the added material (machining allowance) to be removed should not exceed 0.5 mm (0.020 in), which is about the average thickness of the dense, fine-grained skin of the casting. (See Fig. 5.4.18.) Deeper cuts could open up unsightly subsurface porosity and possibly affect function. The machining allowance should not be less than 0.25 mm (0.010 in) to avoid excessive tool wear.

Holes for tapping should be cored rather than drilled. A drilling operation is eliminated, and the tap will cut into dense material for a higher-quality thread. Tapping into

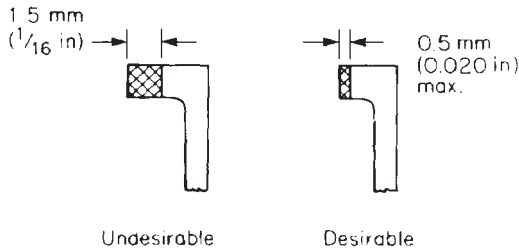


FIGURE 5.4.18 Limit machining allowance to 0.25 to 0.50 mm (0.010 to 0.020 in).

a porous substructure laid open by drilling can result in tap breakage.

If an area to be machined covers ejector-pin locations, their impressions should be left standing to 0.4 mm (0.015 in)—the usual specification is 0 to 0.4 mm (0.015 in) depressed—so that they are removed in machining.

Flash and Gate Removal

Designers should be realistic about the degree of flash and gate removal they specify. With complex castings having massive core slides, the cost of complete removal by a combination of die trimming and hand operations can be as much as, or even considerably more than, the cost of the raw casting.

A well-built trimming die will remove flash almost to the most extremely drafted

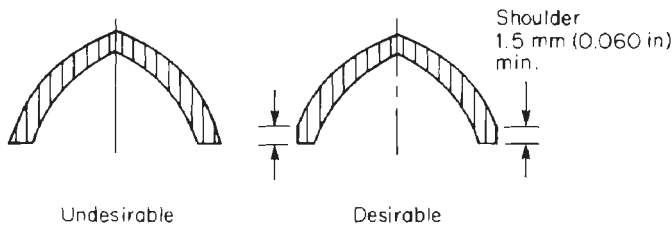


FIGURE 5.4.19 Allow a 1.5-mm (0.060-in) minimum height shoulder at parting line for more nearly complete removal of in-gates by the trimming die.

point of the casting wall. But because the cutting edges wear, an allowance must be made. Commercial die castings are considered to be adequately trimmed if flash and gates are removed to within 0.38 mm (0.015 in) of the casting wall or, in the case of very heavy gates more than 2.2 mm (0.090 in) thick, within 0.75 mm (0.030 in).

Designers should avoid an angled junction of an external wall with the parting line. It is preferable to add a minimum-draft shoulder at the parting line, as shown in Fig. 5.4.19 so that most of the gate material will come away in trimming.

If the sidewalls of the part are intricately configured, a trimming tool to match would be expensive and hard to maintain. In such situations, it is advisable to add a shoulder between wall detail and parting line to allow for use of a single trimming die or a lathe-turning operation to remove gates and flash. (See Fig. 5.4.20.)

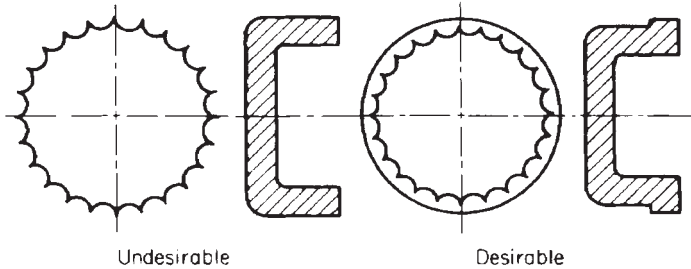


FIGURE 5.4.20 Provide a shoulder between parting line and scallop to simplify gating and trimming.

When sidewalls are formed in both halves of the die, mismatch will complicate flash and gate removal. If possible, the part should be redesigned to a straight parting line. Flash is then at the bottom of the walls, where it is more readily trimmable, and an unsightly seam line on the sidewalls is avoided. A further benefit is elimination of the costly stepped parting line in the die.

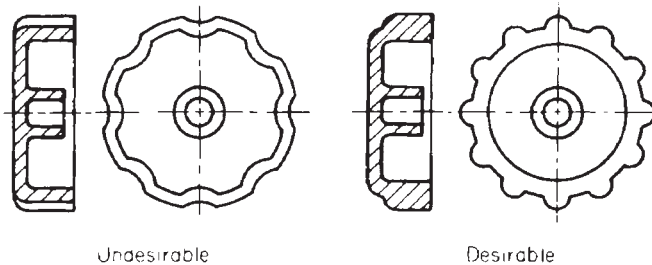


FIGURE 5.4.21 Convex finger grips for a die-cast knob are easier to mill into the die than concave notches.

Die-Sinking Economics

In machining cavities, the die builder is working basically with a circular cutter. If the casting is designed with convex features in outside walls, as in Fig. 5.4.21, it is a straightforward job to mill the corresponding concavities into the steel. Likewise, a nonsymmetrical rib end can be put into the steel, though at considerable cost, but symmetrical features are easy.

Lettering

Many parts designed for die casting need trademarks, part numbers, indications for dials, etc., incorporated into their surfaces. There are two alternatives. The easy way is to specify that the characters be raised in the casting. This can be accomplished by relatively inexpensive engraving of the die. If the characters are to be depressed into the casting, however, all the background steel on that face of the die must be painstakingly removed around the characters.

If the designer wants the economy of raised characters but does not wish them to project above the surrounding surface, a raised pad can be incorporated into the die to form a depressed area in the casting. Then when the pad is engraved, the lettering will come out flush.

There are some basic rules to follow for lettering: minimum character width, 0.25 mm (0.010 in), to allow for filling; character height, 0.25 to 0.5 mm (0.010 to 0.020 in), also to allow for filling; and at least 10° draft for clean ejection. Lettering cannot be located on sidewalls in two-part dies, as it would constitute an undercut. It is restricted to features parallel to the parting line or on sidewalls formed by core slides.

Surface Design

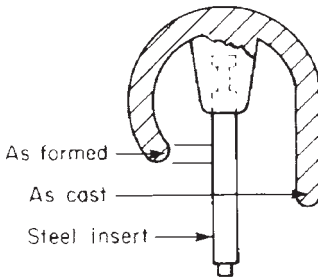


FIGURE 5.4.22 A small knob cast onto a steel insert and formed to final shape by spinning.

Large, plain areas on a die casting are vulnerable cosmetically because any slight casting imperfection will be readily visible. The surface may be sanded or polished, but a less expensive means of resolving the problem is to mask irregularities by designing in ribs, serrations, other details, or mold texturing that “breaks up” the surface of the part. Sidewalls can be textured by using some of the shallower options, provided they are drafted sufficiently to prevent the texture forming an undercut.

Integral Means of Assembly

Die casting offers the designer wide latitude in providing appendages that make assembly to other parts quick and simple. These features are of two general types: cast-in studs to receive spring clips and cast-in lugs, rivets, and lips that are deformed to effect closure. All the alloys can be used with the spring-retainer approach, but zinc alloy, because of its ductility and ready formability, is favored when deformation is the means of assembly. These fastening methods are discussed and illustrated in Chap. 7.5.

Spinning is a handy procedure for permanently assembling a zinc die casting to another component. This technique also may be used to form a variety of noncastable but very useful shapes like the one shown in Fig. 5.4.22.

DIMENSIONS AND TOLERANCES

The as-cast dimensional variations of a die casting, as with all casting processes, depend in part on the size of the casting. This dependency is largely due to thermal expansion and contraction of both the die and the casting. The die expands at operating temperatures, and the casting shrinks after it leaves the die. Both of these vary linearly. Variations in die operating temperatures and the temperature of the molten metal entering the die add to the need for a design tolerance on die-casting dimensions.

In designing the die for a particular part, the die builder enlarges the dimensions by a “shrink factor,” usually 0.6 percent, to account for die expansion and metal contraction (the former being about half the latter in most situations). This works out well for a dimension between points that are not restrained during contraction, but when the metal shrinks onto a constraining feature such as a massive core, shrinkage will be less.

Tolerances across the parting line and between core slides and main die blocks must be greater because of the clearances that are incorporated into these features in the die to enable them to function at elevated temperatures. Recommended tolerances also allow for gradual wear in die components over the life of tooling. This is a significant factor. Another is warpage. In production, in the time taken for a casting to cool to room temperature, varying rates of contraction, a function of part design, can produce warpage. Such distortion is common in all castings, particularly large-area, thin shapes.

If dimensional limits in the as-designed part must be exceptionally close, the impact on the costs of die development and casting production needs to be weighed carefully to determine whether the close-tolerance requirement might be handled more economically in a secondary machining operation.

TABLE 5.4.7 Recommended Tolerances for Die-Casting Dimensions Determined by Cavity Dimensions in Either Half of the Die, mm (in)

	Die-casting alloy			
	Zinc	Aluminum	Magnesium	Copper
For critical dimensions				
Dimensions to 25 mm (1 in)	$\pm 0.08 (\pm 0.003)$	$\pm 0.10 (\pm 0.004)$	$\pm 0.10 (\pm 0.004)$	$\pm 0.18 (\pm 0.007)$
Each additional 25 mm over 25 to 300 mm (each additional in over 1 in to 12 in)	$\pm 0.025 (\pm 0.001)$	$\pm 0.038 (\pm 0.0015)$	$\pm 0.038 (\pm 0.0015)$	$\pm 0.05 (\pm 0.002)$
Each additional 25 mm over 300 mm (each additional in over 12 in)	$\pm 0.025 (\pm 0.001)$	$\pm 0.025 (\pm 0.001)$	$\pm 0.025 (\pm 0.001)$	
For noncritical dimensions				
Dimensions to 25 mm (1 in)	$\pm 0.25 (\pm 0.010)$	$\pm 0.25 (\pm 0.010)$	$\pm 0.25 (\pm 0.010)$	$\pm 0.35 (\pm 0.014)$
Each additional 25 mm over 25 to 300 mm (each additional in over 1 in to 12 in)	$\pm 0.038 (\pm 0.0015)$	$\pm 0.05 (\pm 0.002)$	$\pm 0.05 (\pm 0.002)$	$\pm 0.08 (\pm 0.003)$
Each additional 25 mm over 300 mm (each additional in over 12 in)	$\pm 0.025 (\pm 0.001)$	$\pm 0.025 (\pm 0.001)$	$\pm 0.025 (\pm 0.001)$	

TABLE 5.4.8 Parting-Line Tolerances, in Addition to Linear-Dimension Tolerances (Based on Single-Cavity Die)*

Projected area of die casting, cm ² (in ²)	Additional tolerances, die-casting alloy, mm (in)			
	Zinc	Aluminum	Magnesium	Copper
Up to 300 (50)	±0.10 (± 0.004)	±0.13 (±0.005)	±0.13 (±0.005)	±0.13 (±0.005)
300–600 (50–100)	±0.15 (±0.006)	±0.20 (±0.008)	±0.20 (±0.008)	
600–1200 (100–200)	±0.20 (±0.008)	±0.30 (±0.012)	±0.30 (±0.012)	
1200–1800 (200–300)	±0.30 (±0.012)	±0.40 (±0.015)	±0.40 (±0.015)	

*Parting-line tolerances, in addition to linear-dimension tolerances, must be provided when the parting line affects a linear dimension. The above tolerances are to be added to linear tolerances worked out for a dimension as provided in Table 5.4.7.

TABLE 5.4.9 Moving-Die-Part Tolerances, in Addition to Linear-Dimension Tolerances*

Projected area of die casting portion, (cm ² in ²)	Additional tolerances, die-casting alloy, mm (in)			
	Zinc	Aluminum	Magnesium	Copper
Up to 60 (10)	±0.10 (± 0.004)	±0.13 (±0.005)	±0.13 (± 0.005)	±0.25 (±0.010)
60–120 (10–20)	±0.15 (±0.006)	±0.20 (±0.008)	±0.20 (±0.008)	
120–300 (20–50)	±0.20 (±0.008)	±0.30 (±0.012)	±0.30 (±0.012)	
300–600 (50–100)	±0.30 (±0.012)	±0.40 (±0.015)	±0.40 (±0.015)	

*Moving-die-part tolerances, in addition to linear-dimension tolerances and parting-line tolerances, must be provided when a moving die part affects a linear dimension.

Because of the guesswork involved in developing a die design, the ultimate die casting will invariably have some dimensions that fall outside normal commercial tolerances. When such dimensions do not impact form, fit, or function, “buy-off” and corresponding print changes are recommended. Unnecessary corrections are costly; they adversely affect die life, and they will only delay production.

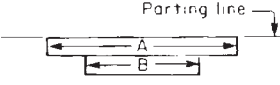
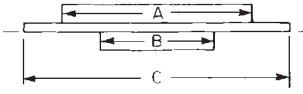
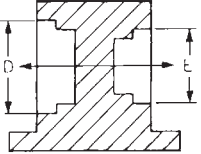
Table 5.4.7 presents recommended tolerances for dimensions determined by cavity dimensions in either half of the die. Table 5.4.8 provides additional tolerances to be applied if the dimension crosses the die-parting line. Table 5.4.9 provides additional tolerances to be applied if the dimension is affected by moving die cores.

Concentricity tolerance recommendations for various conditions are shown in Table 5.4.10. Commercial flatness tolerances prescribe that a die casting be flat within 0.003 in/in of the maximum dimension measured corner to corner, with a minimum standard of 0.008 in for parts 3 in or less in dimension, as measured by a feeler gauge on a surface plate. A die caster agreeing to meet the tolerance will mechanically straighten the part to this standard if necessary.

Tighter-than-commercial tolerances often can be accommodated, but the procedures required cannot be established precisely until sample castings are subjected to trials. Extremely close tolerances may involve stress relieving and special straighten-

*This section was contributed by Fred H. Jay, Manager, Sales and Applications Engineering, Zinc Components Division, Fisher Gauge Limited, Petersburg, Ontario.

TABLE 5.4.10 Recommended Concentricity Tolerances

1. Surfaces in fixed relationship in one die section	Diameter of largest surface <i>A</i>	Recommended tolerance, TIR
	75 mm or less (3 in or less)	0.1 mm (0.004 in)
	Over 75 mm (over 3 in)	0.1 mm plus 0.0015 mm/ additional mm (0.004 in plus 0.0015 in/ additional in)
2. Surfaces formed by opposite sections of die, based on single-cavity die	Projected area of die casting, e.g., area of <i>C</i>	Additional tolerance (added to basic tolerance)
	Less than 320 cm ² (50 in ²)	0.38 mm (0.015 in)
	320–650 cm ² (50–100 in ²)	0.50 mm (0.020 in)
	650–1300 cm ² (100–200 in ²)	0.75 mm (0.030 in)
	1300–2000 cm ² (200–300 in ²)	1.0 mm (0.040 in)
3. Surfaces formed by two moving die members	Projected area of moving die member, e.g., <i>D</i> or <i>E</i>	Additional tolerance added to basic tolerance for each die member
	Less than 60 cm ² (10 in ²)	0.15 mm (0.006 in)
	60–130 cm ² (10–20 in ²)	0.30 mm (0.012 in)
	130–320 cm ² (20–50 in ²)	0.45 mm (0.018 in)
	320–650 cm ² (50–100 in ²)	0.63 mm (0.025 in)

ing fixtures. The designer is cautioned against specifying close-tolerance straightness in a design unless it is absolutely necessary, for it is costly to obtain.

MINIATURE DIE CASTINGS*

Die castings under 86 g (3 oz) are classified by some authorities as miniature die castings. Although most design considerations are identical, and although designers will always err on the safe side if they adhere to the principles and recommendations covered above, there are also significant differences between regular-size and miniature die castings:

1. Machines for miniature die casting (virtually always hot-chamber machines) are very often special machines that are highly automatic, combining gate and flash removal in the same operation. Tooling also is often special, in that it is designed for a specific machine and not of standard configuration.
2. Machines are usually quick-cycling, having output rates up to 60 cycles/min.



FIGURE 5.4.23 Selection of flash-free miniature zinc die castings.
(Courtesy Fisher Gauge Limited.)

3. Zinc miniature die castings can, in some instances, be cast flash-free with little or no draft.
4. Again with zinc (the normal material for miniature die castings), small cored holes down to about 0.5 mm (0.020 in) can be produced. Specialized techniques permit coring center bores with walls parallel within 0.01 mm (0.0005 in).
5. Tolerances with miniature zinc die castings can be held to closer values than those presented in Tables 5.4.7 through 5.4.10. Tolerances of ± 0.025 mm (± 0.001 in) are routinely feasible. Cored holes can be located within 0.025 mm (0.001 in) of true position.
6. All the preceding factors—high precision, fast cycling, and special tooling and equipment—point to high production quantities as being most advantageous. Production quantities from a few thousand to tens of millions are the province of miniature die castings. Figure 5.4.23 illustrates typical miniature die castings.